GOES-R AWG Product Validation Tool Development

Land Surface Temperature

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LST Product Team

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- **LST Product Team**
  - *Bob Yu (Lead)*
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  - *Robert Hale*
- Others
  - » Shuang Qu (AIT collaborator)
  - » Wei Guo (Proxy data)
  - » Tong Zhu (Proxy data)

Outline

- GOES-R LST Products
- Validation Strategies
- Routine Validation Tools
- “Deep-Dive” Validation Tools
- Ideas for the Further Enhancement and Utility of Validation Tools
- Summary

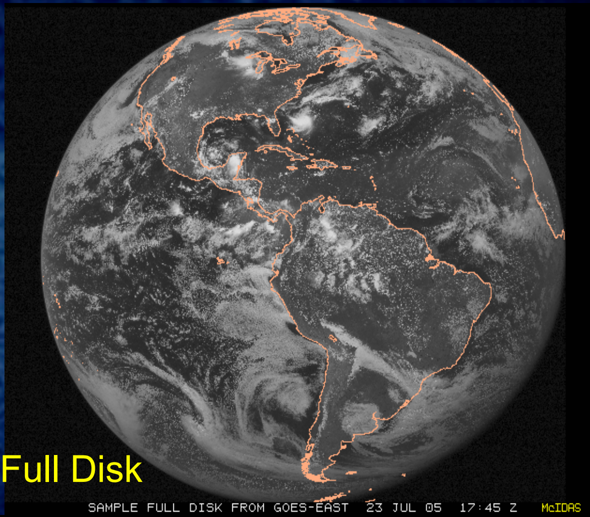
LST Products

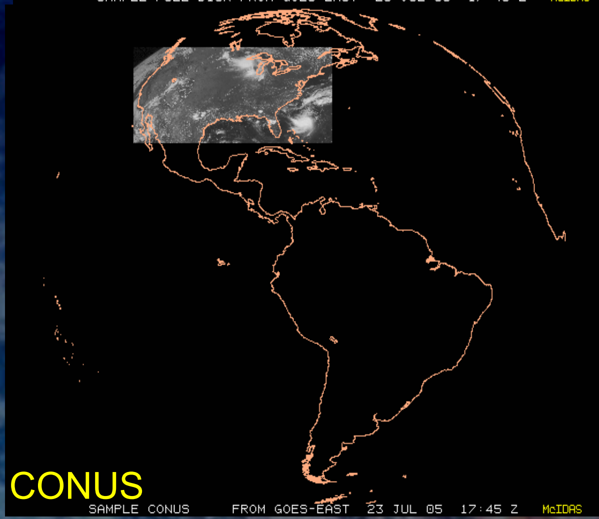
- The ABI Land Surface Temperature (LST) algorithm generates the baseline products of land surface skin temperatures in three ABI scan modes: *Full Disk, CONUS, Mesoscale.*;

- Meets the GOES-R mission requirements specified for the LST product;

- Has a good heritage, will add to the LST climate data record;

- Simplicity for implementation/ease of maintenance, operational robustness, and potential for improvement.





Products

Specifications

Product	Accuracy	Precision	Range	Refresh Rate	Resolution
LST (CONUS)	2.5 K	2.3 K	213 ~ 330 K	60 min	2 km
LST (Full Disk)	2.5 K	2.3 K	213 ~ 333 K	60 min	*10 km*
LST (Mesoscale)	2.5 K	2.3 K	213 ~ 330 K	60 min	2 km

Qualifiers

Product	Temporal Coverage	Product Extent	Cloud Cover Conditions	Product Statistics
LST (CONUS)	Day and Night	LZA < 70	Clear Conditions associated with threshold accuracy	Over specified geographic area
LST (Full Disk)	Day and Night	LZA < 70	Clear Conditions associated with threshold accuracy	Over specified geographic area
LST (Mesoscale)	Day and Night	LZA < 70	Clear Conditions associated with threshold accuracy	Over specified geographic area

Validation Strategies

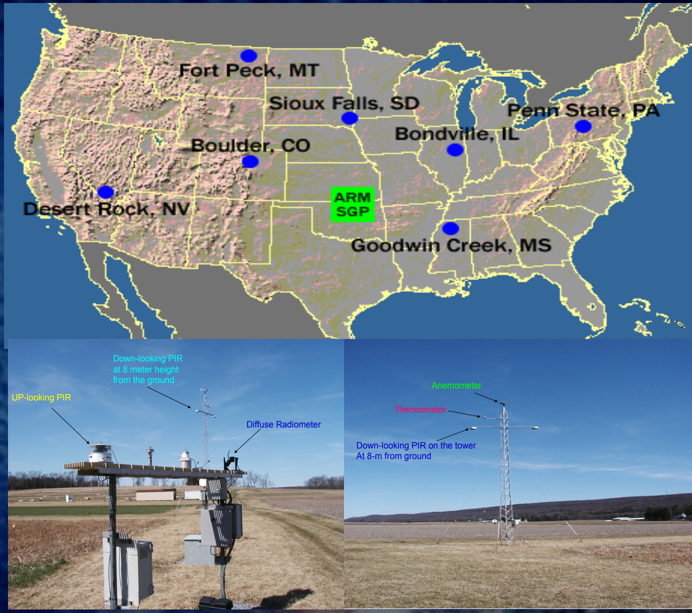
- Issues in satellite LST validation
  - » Satellite data problems
    - – *Instrument calibration, noise, spectral stability*
    - – *illumination and observation geometry*
  - » Ground data problems
    - – *Instrument calibration, spectral response*
    - – *broadband surface emissivity*
    - – *Spatial incompatibility to satellite observations*
  - » High temporal variability of LST
  - » Satellite LST algorithm error (coefficients, emissivity, clouds, etc.)
- Validation needs
  - » discrimination among the above problems as much as possible
  - » use realtime cal/val info from other products to identify problem cascades (instrument noise > cloud detection > LST)
  - » need parallel cal/val system for ground observations

Validation Strategies

- Utilize existing ground station data
  - » Stations under GOES-R Imager coverage
  - » Stations under MSG/SEVIRI coverage
- Ground site characterization
- Stringent cloud filtering
- Multiple comparisons: satellite *vs* satellite, satellite *vs* ground station.
- Direct and indirect comparisons
- International cooperation

Validation Strategies

- **Ground truth data sets**
  - » Surface Radiation Budget Network (SURFRAD) – 7 operational sites in US
    - – Radiometer measuring broadband radiation every 3 minutes
    - – Available within a day or two of observation
    - – Instrument calibrated annually and well maintained
  - » Climate Reference Network (CRN) – up to 122 stations in US
    - – IR thermometer measuring LST average over hour
    - – Available within a day or two of observation
    - – Lower quality than SURFRAD, but many more stations
  - » We need some data outside US, in Central and South America



SURFRAD Sites

- **Reference data sets**
  - » ASTER data sets coincident with SURFRAD and CRN stations
  - » Hourly LST climatology for SURFRAD and CRN for selected hours
  - » Simulated TOA data set from RTM with variety of surfaces, atmospheres and observation geometries – for derivation of coefficients in algorithm
  - » MODIS monthly emissivities

Validation Strategies

- **Development for routine validation tools**
  - Characterizations of SURFRAD and CRN ground sites
  - Routinely acquired matchup data sets of satellite and ground Data
  - Ground LST estimation
  - Procedures for converting point ground LST to "pixel" ground LST
  - Direct comparisons and statistics for each ground LST *vs* satellite LST for last *x* months
  - Time series plots of selected coincident LST and ground LST for last *x* months

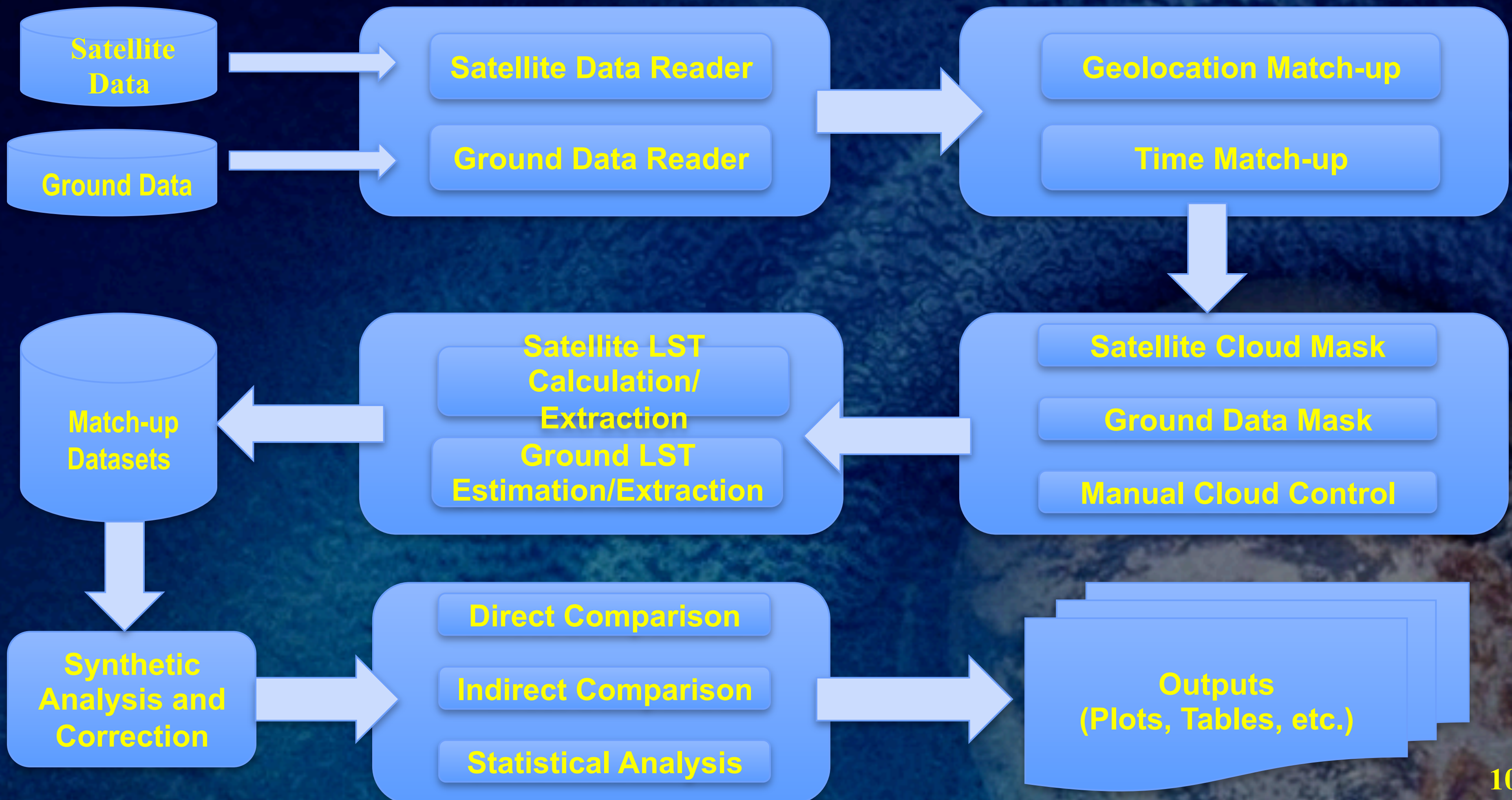
"Routine" Validation Tools
Bulk/overview analysis
Executed soon after product generation
Run routinely
Run within OSPO and STAR
Automated

"Deep Dive" Validation Tools
Detailed/point analysis
Not executed in real-time. May need to wait for other datasets
Run when more detailed analysis of product performance is needed
Run within STAR
Automated and/or Interactive components

- **Development for deep dive validation tools**
  - All of the routine validation tools +
  - Data sets consisting of multiple years of clear radiances coincident with ground LSTs
  - Indirect comparison and statistics for each ground LST *vs* ground LST climatology for last x years
  - Comparisons and statistics for GOES-R LST *vs* other satellite LST
  - Routines for calibrating LST algorithm coeffs using the validation results

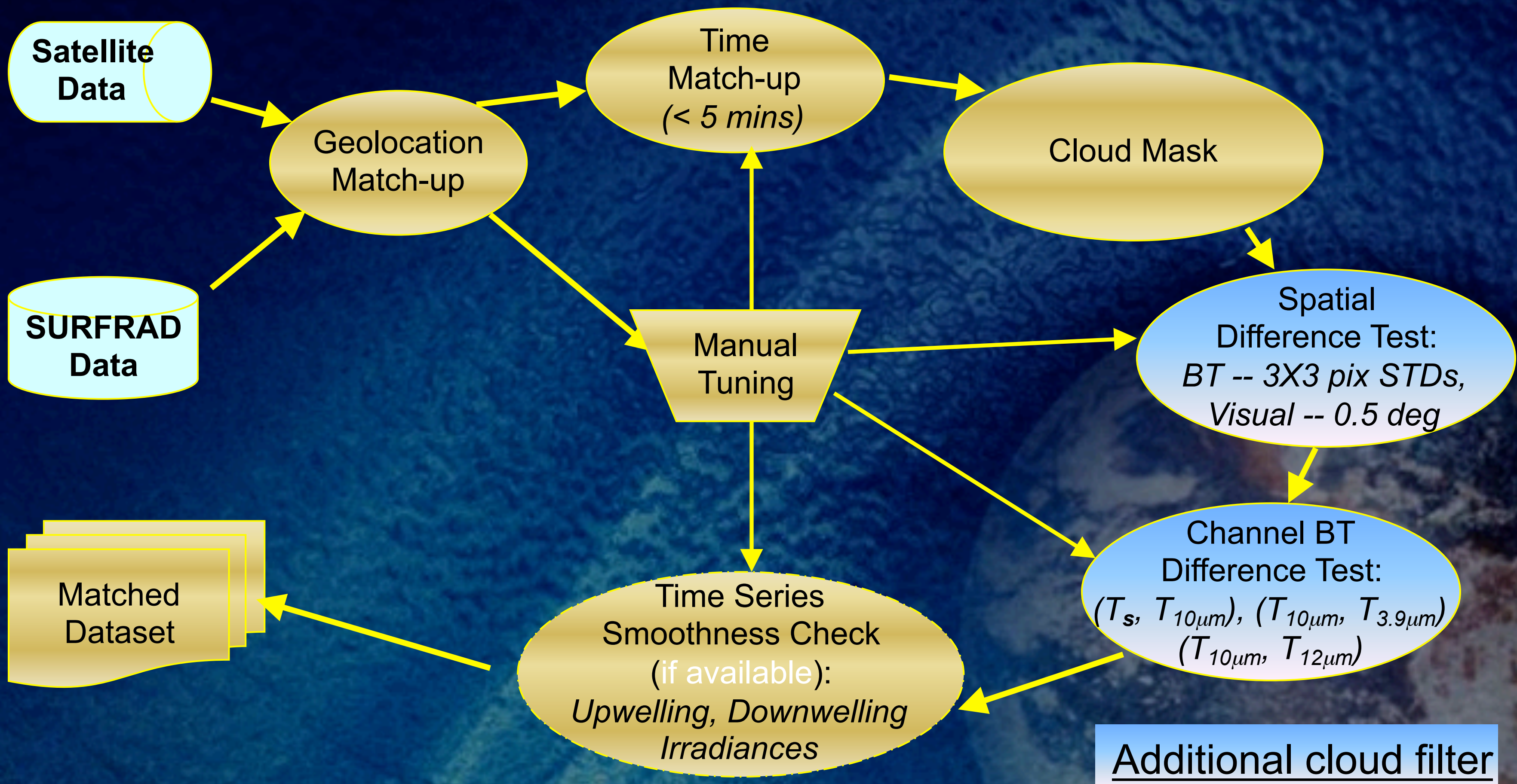
Validation Tools

Components of Validation Tools



Routine Validation Tools

Match-up and Cloud Filtering Process



Note: this flow chart is specifically for GOES Imager
Similar procedure is/will be applied for the ASTER and MODIS/VIIRS data

Routine Validation Tools

Ground LST Estimation

General form :	
$\Phi_{emit} = \Phi_{up} - (1-\varepsilon)\Phi_{down}$; $\Phi_{emit}=\varepsilon\sigma T^4$; $T = (\Phi_{emit}/\varepsilon\sigma)^{1/4}$	Φ_{up} : upward irradiance radiometer received. Φ_{down}: downward irradiance radiometer received Φ_{emit} : surface emitting irradiance

Possible corrections: $T = T + dT^{pir} - dT^{\varepsilon}$

Spectral correction dT^{pir}

Let $d\Phi_e^{pir} = \Phi_e - \Phi_e^{pir}$, the irradiance underestimation due to PIR (radiometer) spectral restriction, a temperature underestimation, $dT^{pir}, = T - T^{pir}$ can be estimated as,

$$d\Phi_e^{pir} = 4\varepsilon\sigma T^3 dT^{pir} = 4\Phi_e \, dT^{pir} / T$$

or, $$dT^{pir} = (d\Phi_e^{pir} / \Phi_e)(T/4)$$

Spectral correction dT^{ε}

Let $d\varepsilon = \varepsilon - \varepsilon^{pir}$ represents emissivity difference between the entire band and (radiometer) broadband, a irradiance underestimation, $d\Phi_e^{emiss} = \Phi_e - \Phi_e^{emiss}$, can be explained by, $d\Phi_e^{emiss} = \sigma T^4 d\varepsilon = \Phi_e d\varepsilon/\varepsilon$, A temperature **overestimation** (note that ε and T^4 are inverse-proportional each other), $dT^{\varepsilon} = T^{\varepsilon} - T$, is

$$dT^{e} = (d\Phi_e^{emiss} / \Phi_e)(T/4)$$

or, $$dT^{e} = (T/4)(d\varepsilon/\varepsilon)$$

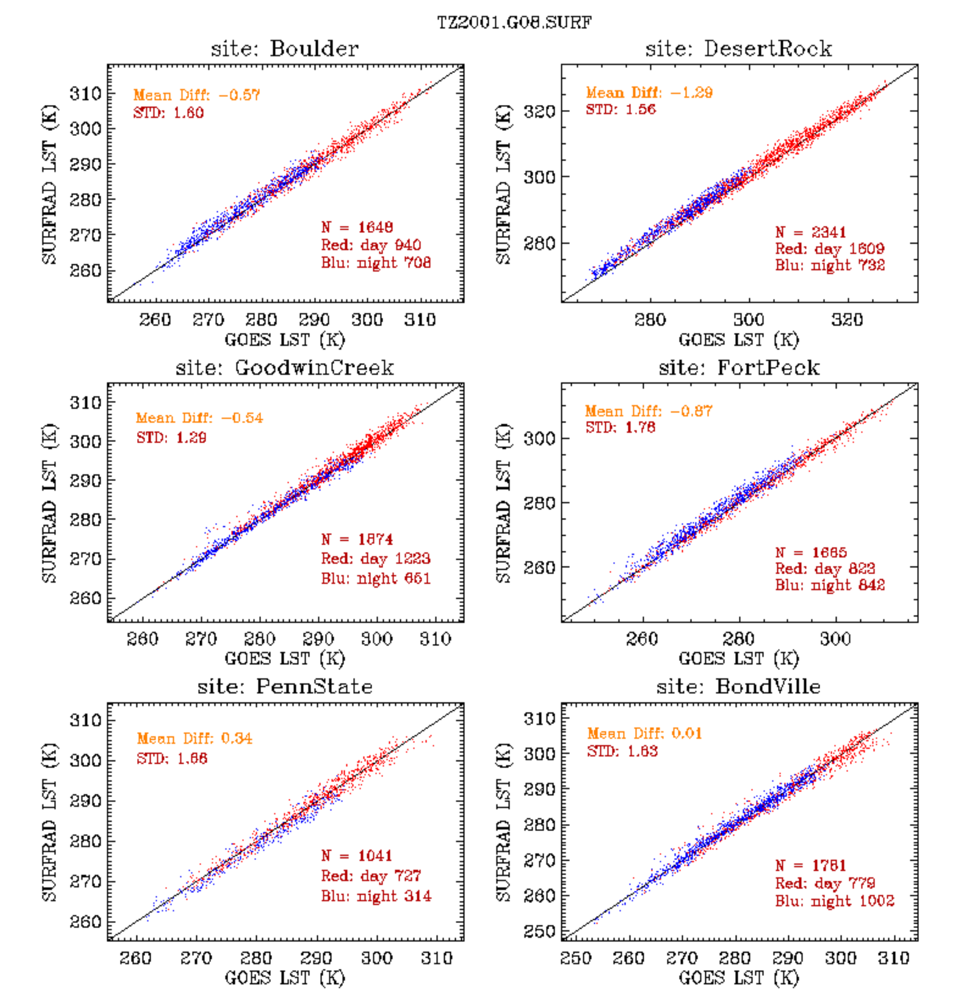
Look-up tables can be pre-calculated for the corrections.

Note: SURFRAD data is spectral corrected

Routine Validation Tools
-- SURFRAD data results

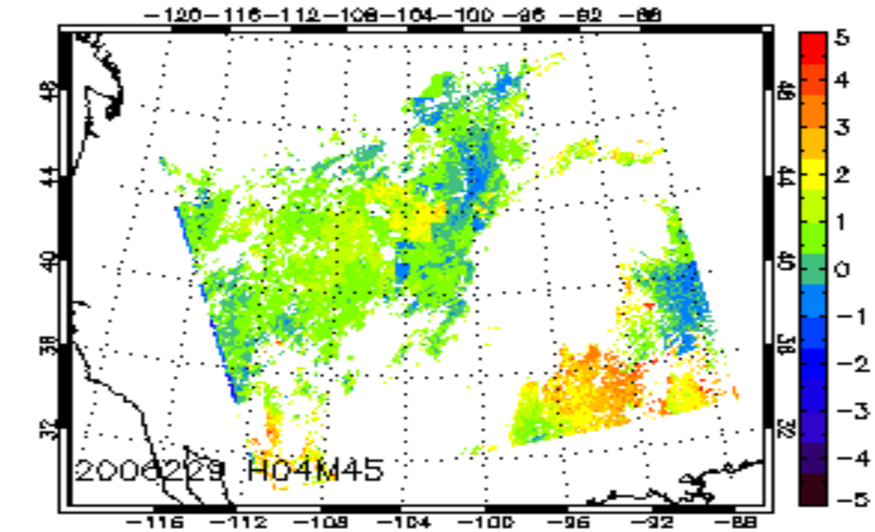
Comparison results of GOES-8 LST using six SURFRAD ground station data, in 2001..

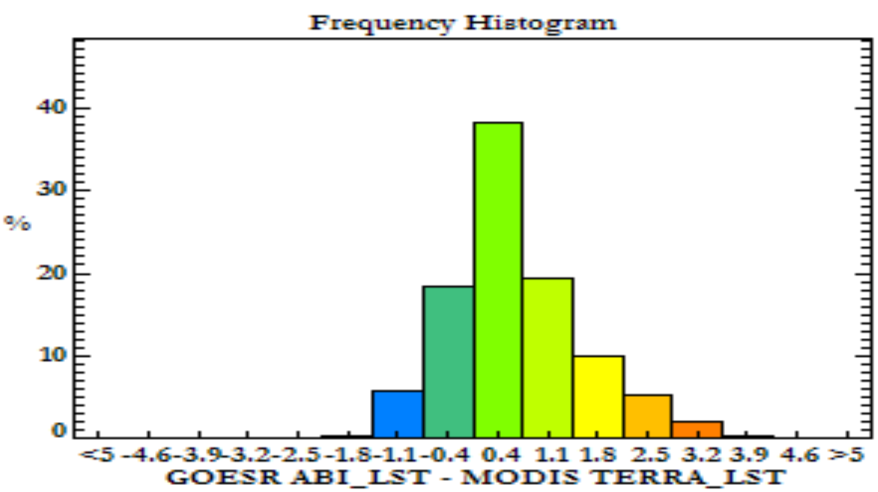
Month	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1	48	17	55	64	107	107	58	48	100	67	100	51
2	43	30	38	38	73	57	55	34	41	54	64	48
3	0	0	51	71	94	62	93	79	41	63	123	34
4	94	18	39	80	81	34	62	61	81	57	139	35
5	71	22	27	59	127	65	75	83	82	45	168	75
6	50	26	82	102	82	51	65	50	86	64	187	60
7	6	4	91	77	40	8	27	38	40	43	173	74
8	43	30	129	113	41	38	82	137	56	45	107	52
9	115	57	95	108	124	49	79	110	116	85	189	98
10	103	38	62	95	184	39	90	79	74	58	115	61
11	114	34	43	129	146	70	64	53	116	53	131	88
12	40	38	67	66	124	71	73	70	107	74	113	56
Total	727	314	779	1002	1223	651	823	842	940	708	1609	732



Numbers (Table, left) and scatter plots (right) of the match-up LSTs derived from GOES-8 Imager data vs. LSTs estimated from SURFRAD stations in year 2001. Data sets in plots are stratified for daytime (red) and night time (blue) atmospheric conditions

Routine Validation Tools
-- 10-week MODIS data





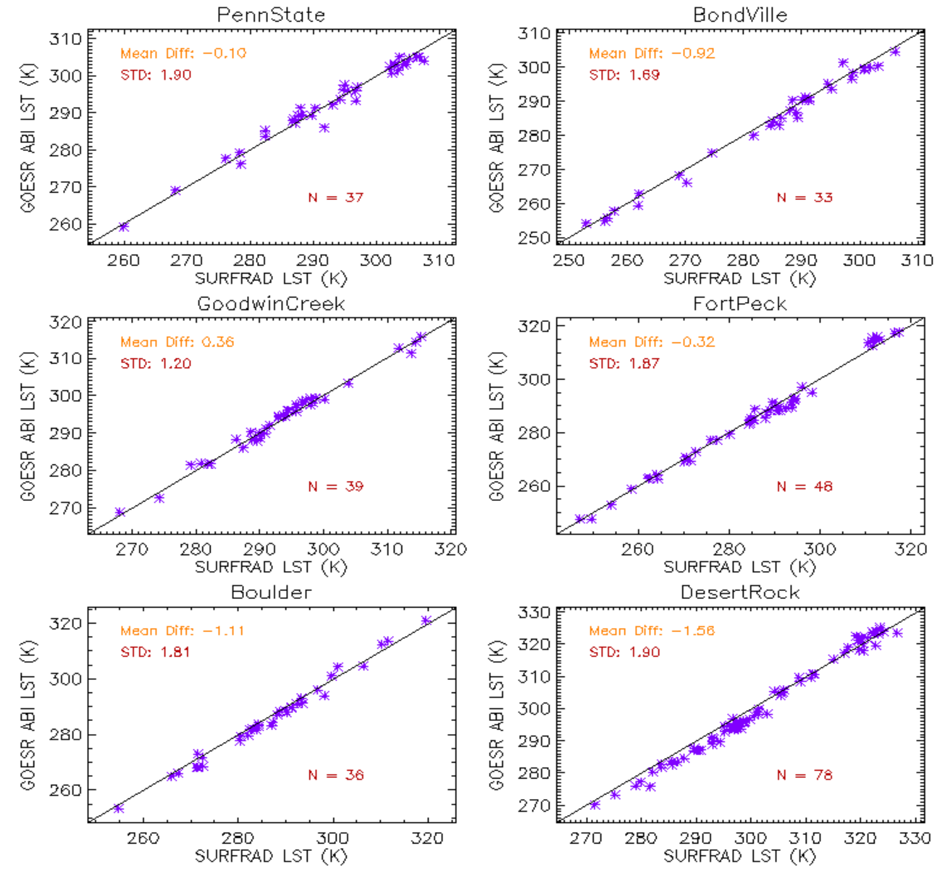
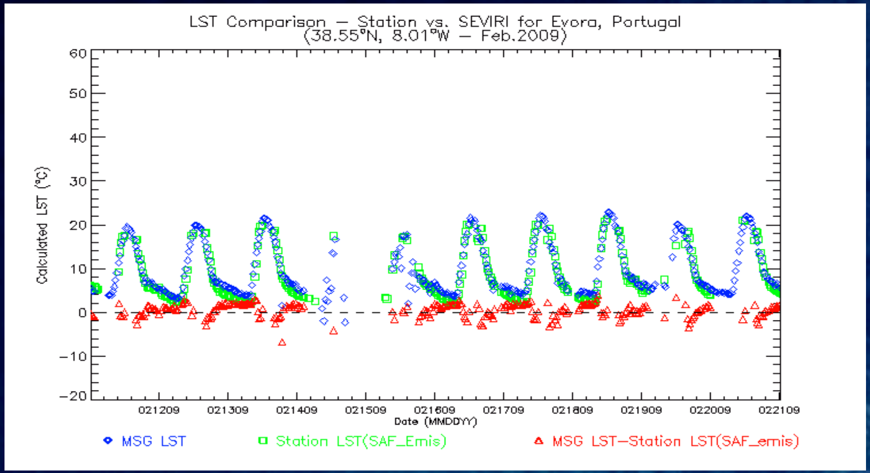
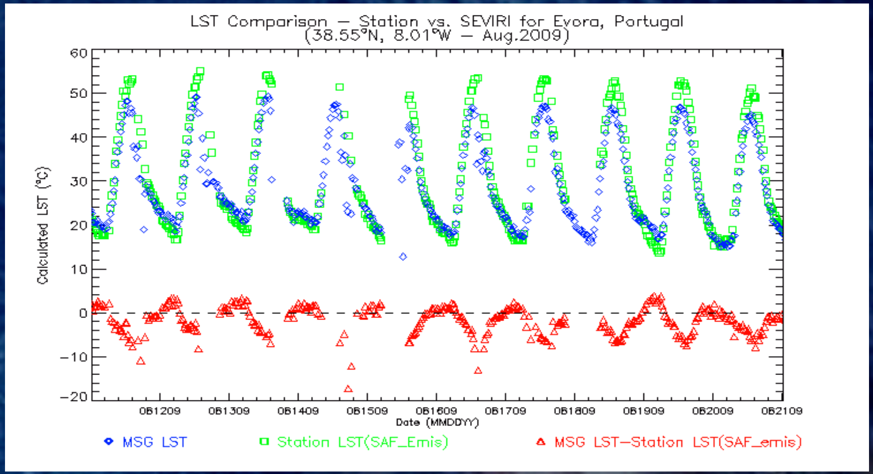


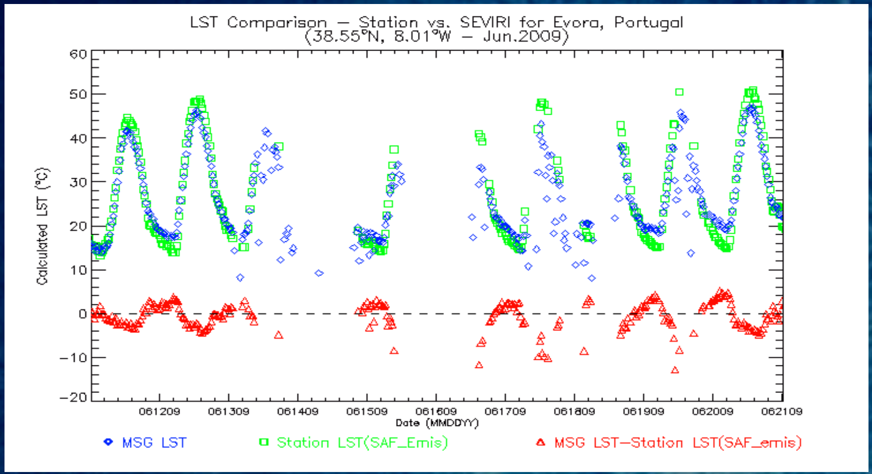
Image and histogram (left) and Scatter plots (right) of GOES ABI LSTs with MODIS TERRA proxy inputs vs. the matched SURFRAD LSTs at each site.

"Routine Validation Tools"
-- SEVIRI Time series monitoring

Comparison samples of SEVIRI-Retrieved LST and station LST at Evora

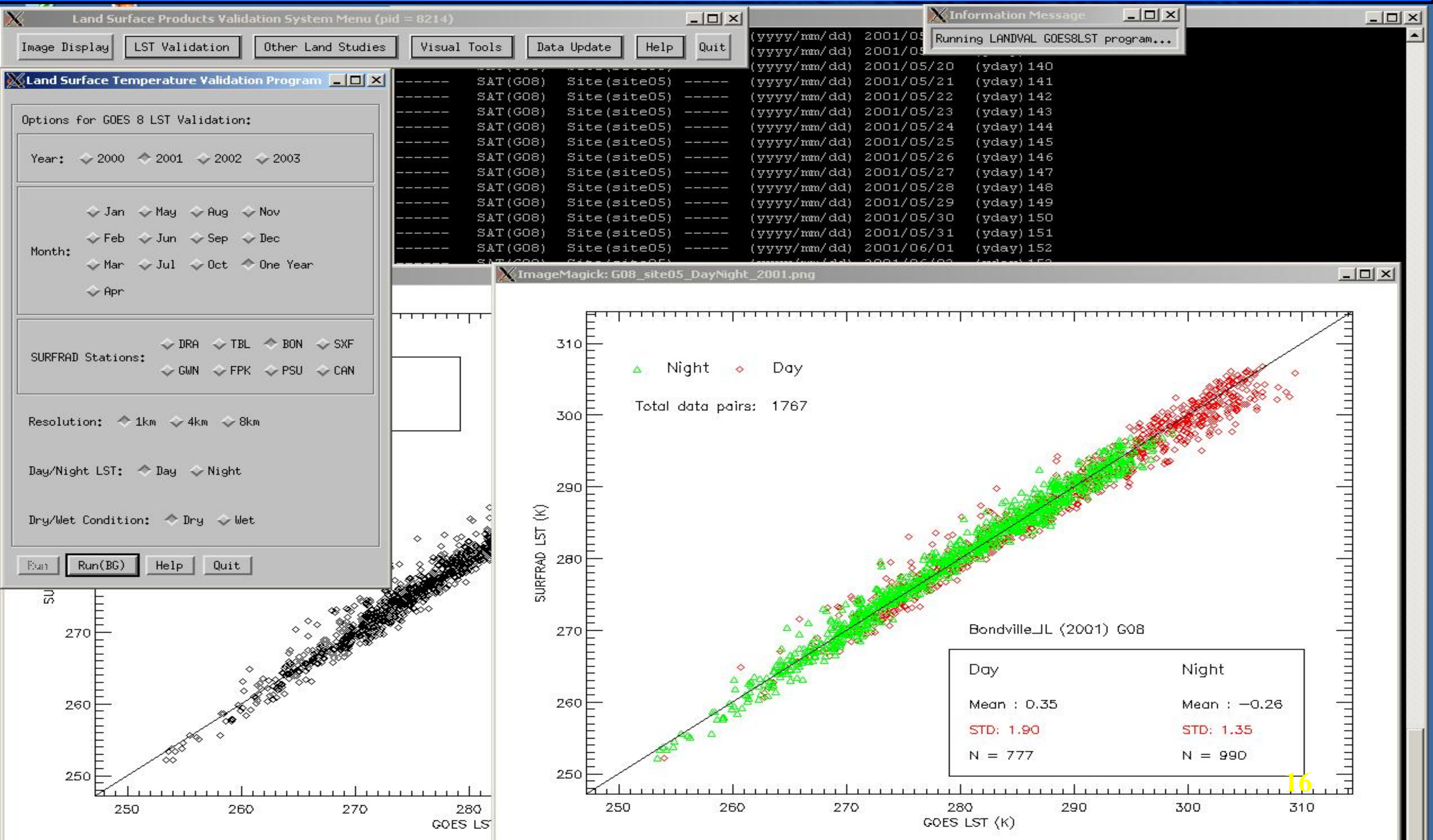






- Daily and hourly observations of satellite and surface LST are stable and repeatable enough to serve as routine monitoring tools.
- Changes that appear in the the observed differences between satellite and surface LST will serve as an "early warning" indicator of problems

Routine Validation Tools
-- A visualization interface



"Deep-Dive" Validation Tools

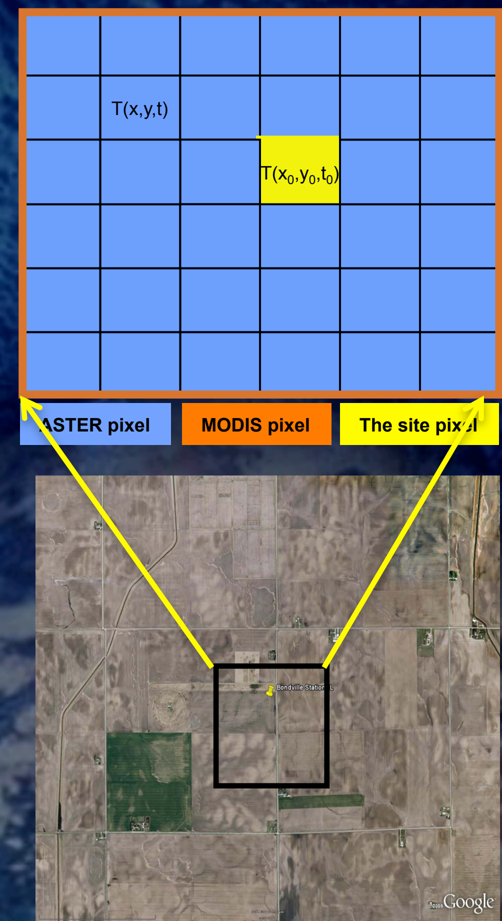
Site characterization analysis using ASTER data— an integrated approach for understanding site representativeness and for site-to-pixel model development

- *Quantitatively characterize the sub-pixel heterogeneity and evaluate whether a ground site is adequately representative for the satellite pixel. The sub-pixels may be generated from pixels of a higher-resolution satellite.*
- *For pixel that is relatively homogeneous, analyze statistical relationship of the ground-site sub-pixel with the surrounding sub-pixels:*
  $\{T(x,y)\} \sim T(x_0,y_0)$
- *Establish relationship between the objective pixel and its sub-pixels (i.e., up-scaling model), e.g.,* $T_{pixel} = T(x,y) + \Delta T$ *(time dependent?)*

Site	MODIS Pixel-SURFRAD		Synthetic Pixel-SURFRAD		Nearest Aster Pixel – Synthetic pixel	
	Mean	StdDev	Mean	StdDev	Mean	StdDev
Desert Rock, NV	-0.44	1.84	2.09	1.69	0.04	0.44
Boulder,CO	-0.49	2.08	1.49	2.90	-0.09	0.67
Fort Peck, MT	0.35	2.52	0.78	1.95	0.38	1.15
Bondville, IL	-0.17	1.51	1.04	1.48	0.03	0.90
Penn State, PA	-1.53	1.91	0.61	1.96	0.04	1.07

Site-to-Pixel Statistical Relationship for 5 SURFRAD sites

The Synthetic pixel/sub-pixel model



Surface heterogeneity is shown in a 4km x 4km Google map (1km x 1km, in the center box) around the Bondville station area

"Deep-Dive" Validation Tools
-- Two-measurement analysis

Linear Approach Model

$$LST_{goes} = \mu_{goes} LST + a + \varepsilon_{goes}$$

$$LST_{surfrad} = \mu_{surfrad} LST + b + \varepsilon_{surfrad}$$

LST -- True LST

LST_{goes} – The GOES LST measurement

$LST_{surfrad}$ – the SUFRAD LST estimation

ε_{goes} – random noise of the GOES LST measurement

$\varepsilon_{surfrad}$ – random noise of the SURFRAD LST estimation

Perform Variation/Co-variation Computation

$$VAR(LST_{goes}) = \mu_{goes}^2 VAR(LST) + \mu_{goes} COV(LST, \varepsilon_{goes}) + VAR(\varepsilon_{goes})$$

$$VAR(LST_{surfrad}) = \mu_{surfrad}^2 VAR(LST) + \mu_{surfrad} COV(LST, \varepsilon_{surfrad}) + VAR(\varepsilon_{surfrad})$$

$$COV(LST_{goes}, LST_{surfrad}) = \mu_{goes}\mu_{surfrad} VAR(LST) + \mu_{surfrad} COV(LST, \varepsilon_{goes}) + \mu_{goes} COV(LST, \varepsilon_{surfrad}) + COV(\varepsilon_{goes}, \varepsilon_{surfrad})$$

Primary Assumptions (noise, measurement independent)

$COV(\varepsilon_{goes}, \varepsilon_{surfrad}) = 0$, $COV(LST, \varepsilon_{goes}) = 0$, $COV(LST, \varepsilon_{surfrad}) = 0$,

Therefore

$$VAR(LST) \approx \frac{COV(LST_{goes}, LST_{surfrad})}{\mu_{goes}\mu_{surfrad}}$$

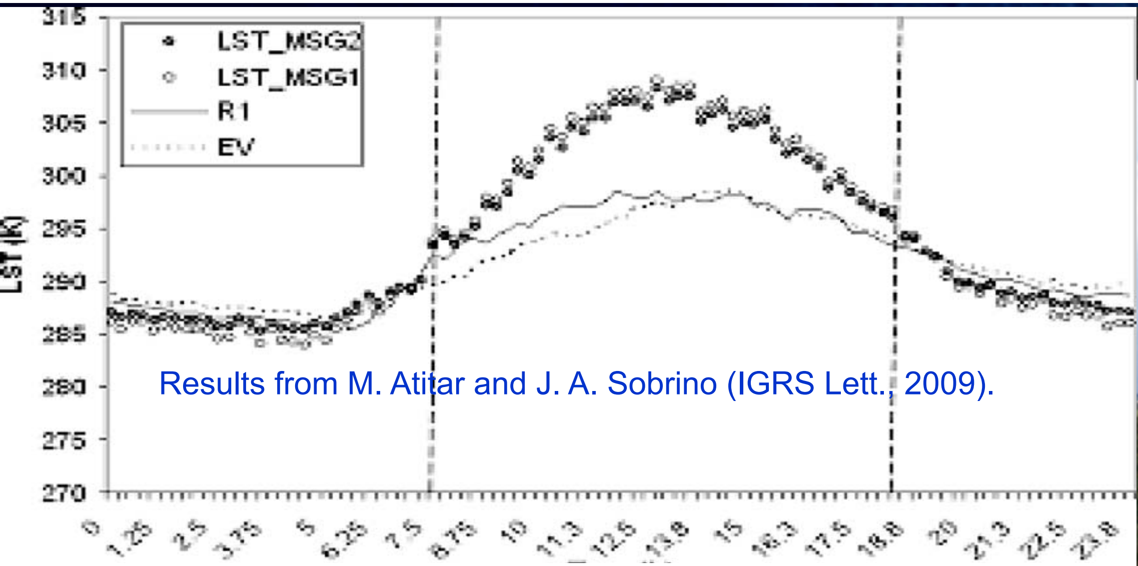
$$\sigma_{goes}^2 \approx VAR(LST_{goes}) - \frac{\mu_{goes}}{\mu_{surfrad}} COV(LST_{goes}, LST_{surfrad})$$

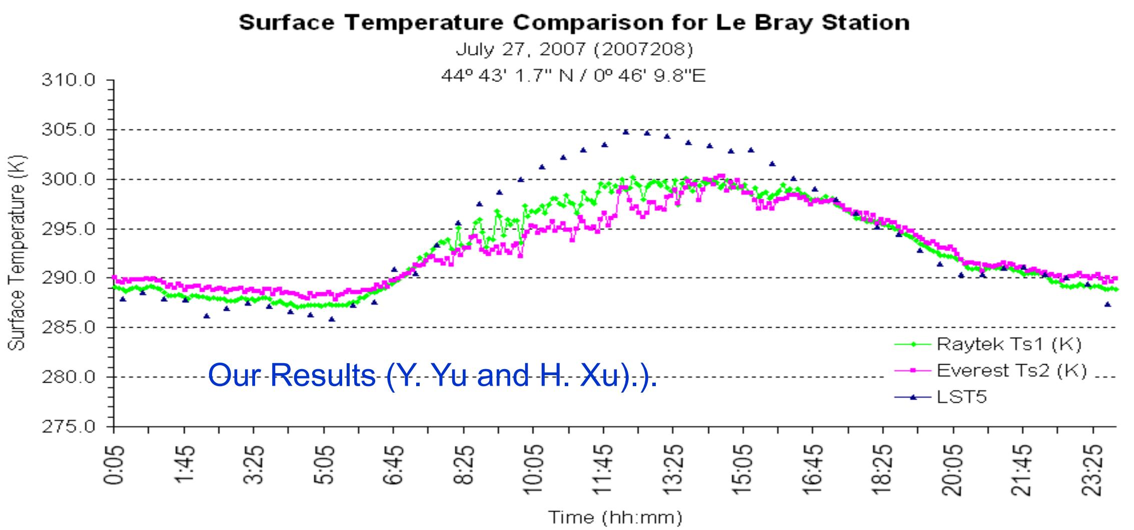
$$\sigma_{surfrad}^2 \approx VAR(LST_{surfrad}) - \frac{\mu_{surfrad}}{\mu_{goes}} COV(LST_{goes}, LST_{surfrad})$$

A two-measurement method is developed for the satellite LST evaluation, which treats the satellite LST and the ground LST as two noise-contained measurements and estimate the satellite LST noise if the ground LST noise is known, or vice versa.

No	$\mu_{goes}/\mu_{surfrad}$	σ_{goes}	$\sigma_{surfrad}$
1	1.05	1.378	0.334
2	1.06	1.239	0.661
3	1.07	1.083	0.870
4	1.08	0.900	1.035
5	1.09	0.669	1.174
6	1.10	0.293	1.230

"Deep-Dive" Validation Tools
-- A field data case study





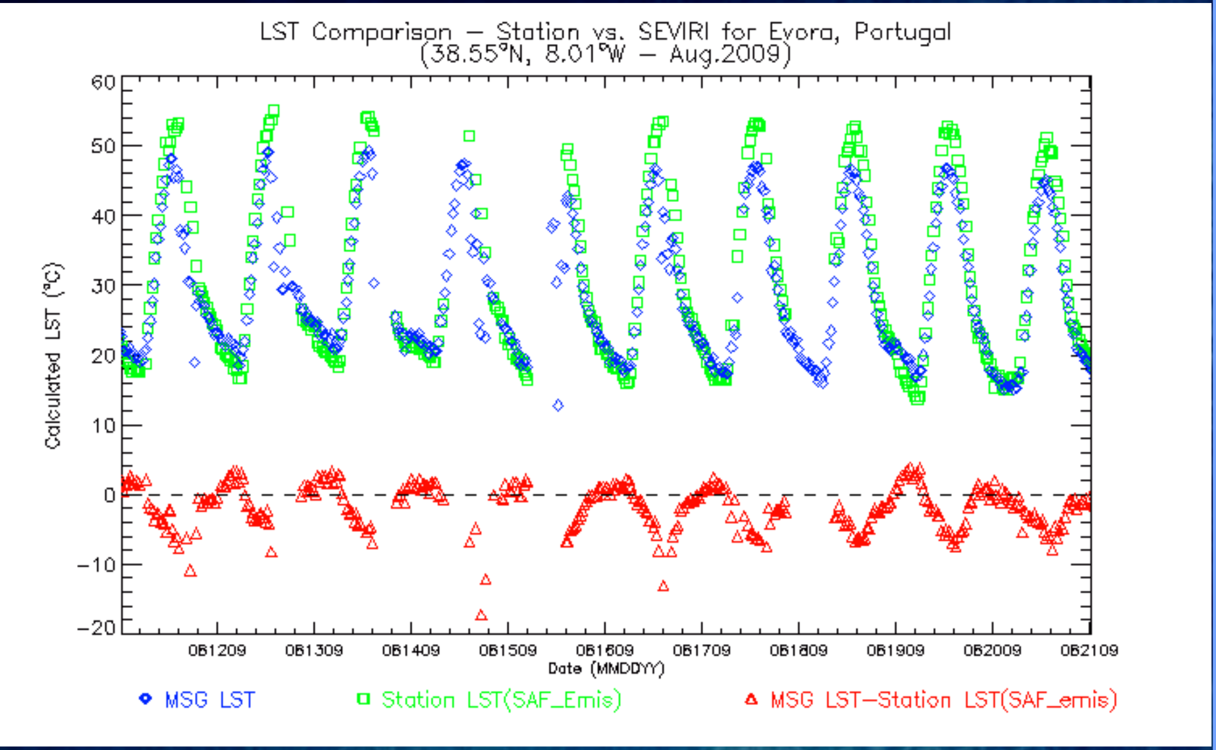
Courtesy by J.A. Sobrino

Field Data ---- a field campaign carried out in the zone of Bordeaux (44◦4301.7 N, 0◦4609.8 W), forest zone of Le Bray. LSTs were derived from two radiometers (Raytek (R) and Everest (Ev)) installed in a tower of 33-m altitude.

We obtained very similar results to Atitar and Sobrino *et al.* (2009).

"Deep-Dive" Validation Tools

Comparison of SEVIRI-Retrieved LST and station LST at Evora



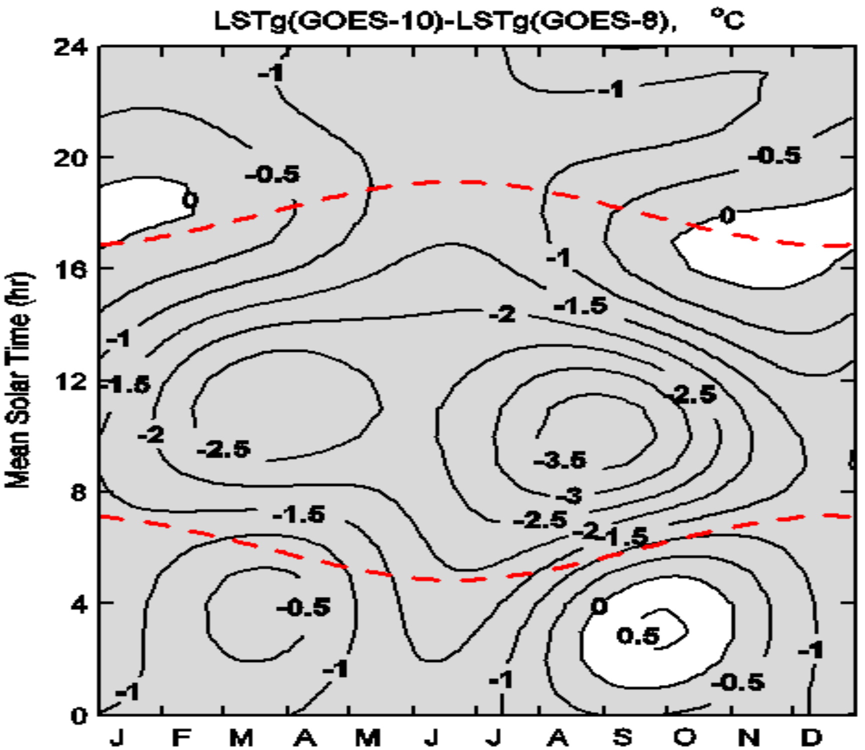
- Apparent diurnal patterns are shown in the 10 days' LST comparison profiles for selected months.
- Comparison of LST diurnal profiles revealed higher station LST than SEVIRI LST around mid-days (i.e. maximum daily LST) and slightly higher SEVIRI LST than station LST at night (with low LST).
- The diurnal differences are larger in warm months.

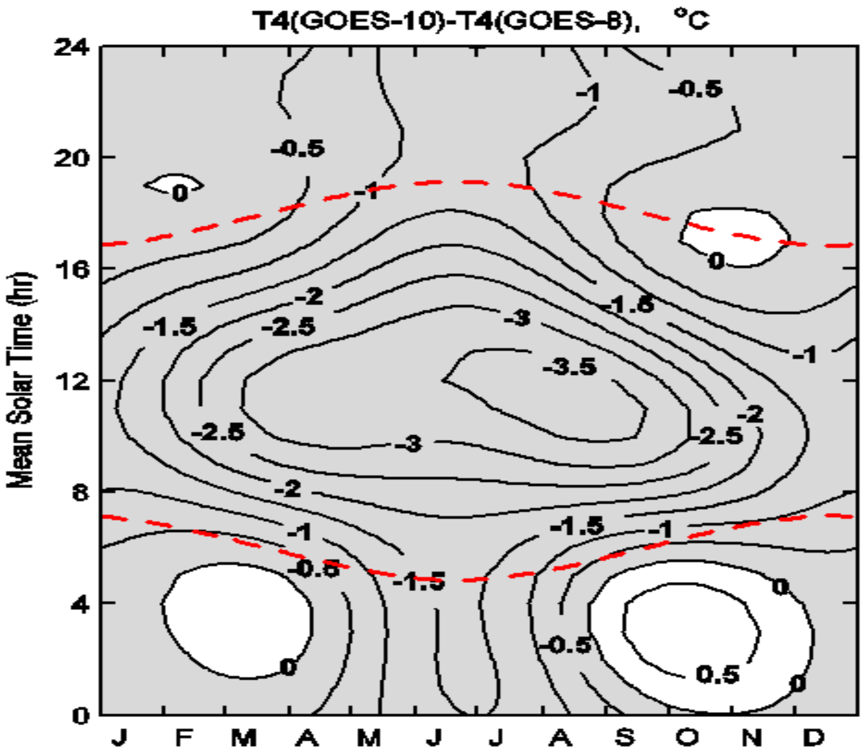
We need to understand and fix this problem

"Deep-Dive" Validation Tools
-- Directional effect study

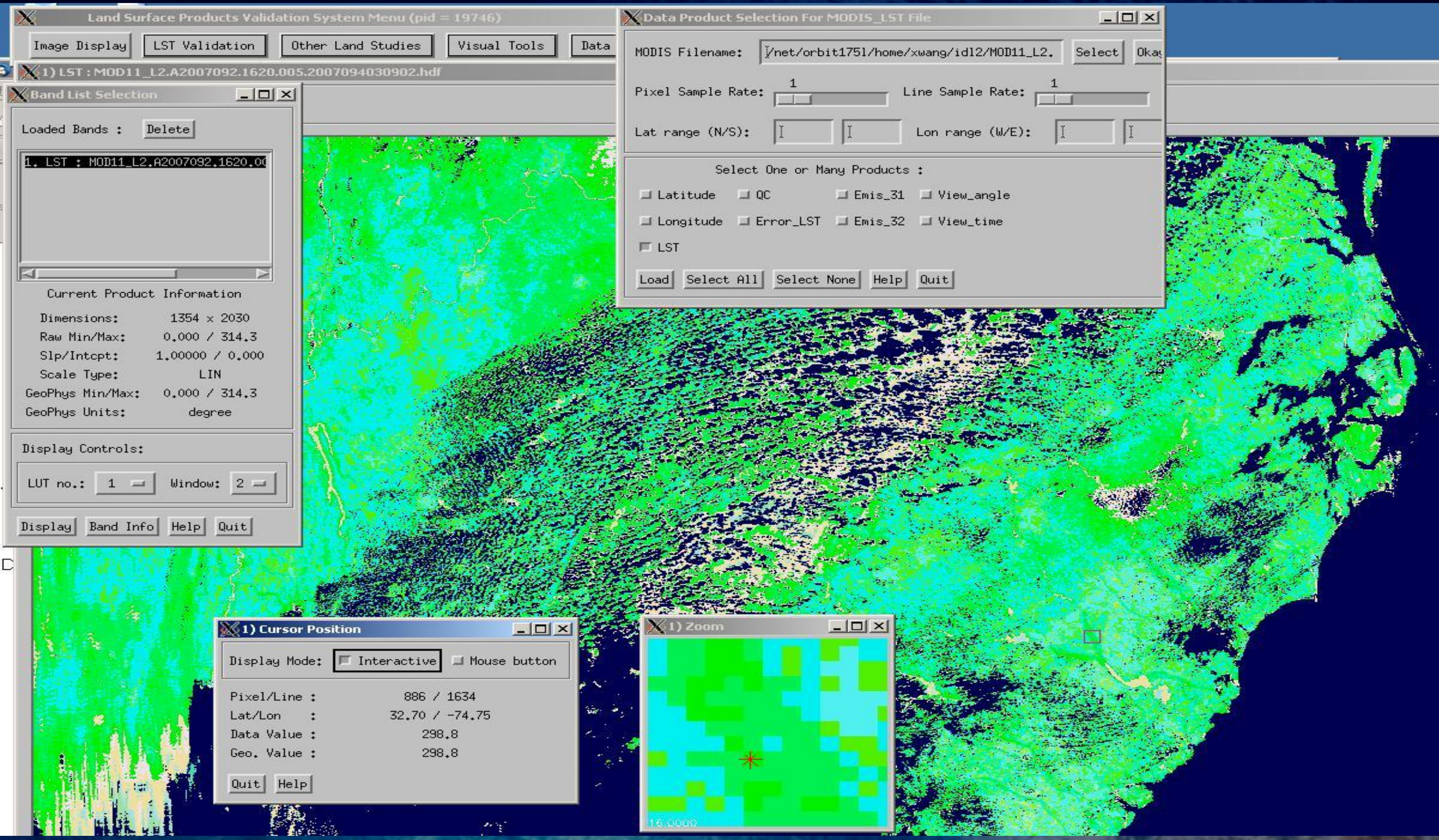
Due to the satellite LST directional properties (surface components, topography, shadowing etc.), the satellite LST can be significantly different from different view angles. Deep dive validation tools may be used for case studies and improved algorithms.

Goodwin Creek, MS, observation pairs are about 510. View Zenith of GOES-8/-10: $42.68^0/61.89^0$





"Deep-Dive"
-- A visualization interface



Ideas for the Further Enhancement and Utility of Validation Tools

- Emissivity comparisons with ASTER Land Surface Emissivity Database (NAALSEDv3) and MODIS Emissivity Data
- Visualization tools (Web server)
- Cloud filtering
- Spot-to-pixel scaling enhancement
- Others?

Summary

- Satellite LST cal/val is complicated by several remote sensing problems
  - » Complexity of land surface temperature – variable at all scales and time frames
  - » Dependence of LST on upstream processing – sat calibration, cloud detection…
  - » Lack of high quality and geographically well-distributed ground truth
- SURFRAD and CRN LST will serve as initial sources of ground truth
- Timeliness and quality of US ground truth allows development of routine validation tools
- Available ground truth and polar satellite LST will allow sufficient data for “deep dive” efforts on the (many) problems left in satellite LST